SOME CONSIDERATIONS FOR LUNAR PRECISE GRAVITY FIELD DETERMINATION FROM ORBITER TRACKING DATA .

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Introduction: Not as on the Earth, on other planets, GPS has little advantages in gravity measurement for planetary research. Doppler tracking and laser ranging have become ordinary approaches for gravity field determination in planetary exploration. With many successful experiences on Earth satellite technologies, satellite-to-satellite tracking (SST) is proved to a prospective way for gravity measurements with high accuracy in planetary research. Therefore, based on the planetary satellite gravimetry methods, orbital dynamics will be applied to determinate gravity field. Meanwhile, this way is also the principal of GEODYN /SOLVE[1] program. How to improve the accuracy of gravity field is the key factor to decide if good interpretation will be acquired. In this paper, Some considerations on gravitational and non-gravitational forces for lunar precise gravity determination from orbiter tracking will be described.

Software Description: Orbital dynamics stands for the relationship between the forces acting on the satellite and orbital elements or satellite positions. The relationship is built by the Newton's force and Keplerian orbital theories[2]. According to the principals, there are two modes in GEODYN program. One is orbital determination from gravity model to orbit generation with Cowell's integration method applied, and the reverse with least-square statistical estimation. With compatibilities in varieties types of orbital data, GEODYN software can deal with data in PCE format, ranging, Doppler, etc.

Essential Factors which Impact Accuracy of Gravity Field Determination: Factors acting on the orbital perturbations are classified into two types, gravitational forces and non-gravitational forces. Gravitational forces include geopotential, gravitation attractions of the Sun, the moon and other planets, especially for Venus and Jupiter, and asphericity of the Earth. Non-gravitational forces include atmospheric drag, solar radiation pressure, Earth radiation pressure, relativistic effects, solid Earth tides. All forces varied at the different height of satellite, related parameters and local conditions. Except for the inaccuracy in measurements, understanding the parameters and local condition is vital to describe in details the related forces, and further, to precise gravity field determination.

On the Earth, asphericity of the Earth leads to a force with about three orders of magnitude smaller than the Earth mass point attraction[3](Fig.1). Besides, the gravitational attraction with the same magnitude as the aspericity of the Earth should be considered. These two corrections above can influence the accuracy of geopotential coefficience, Jn ($n<4$). Earth satellites at low altitudes of several kilometers are affected by atmospheric drag. Atmosphere model is the key factor to evaluate the correction. Solid tide and solar radiation pressure is notable. The exact shape and structure of the satellite is required to get high precise correction. Although the variation from the shadow of the Earth is ramped, it could be solved by GEODYN program. For high-precision application, Earth radiation pressure, solid tides, relativistic effects should be taken into account.

Compared to that on the Earth, different condition and environment on the Moon will lead to absolutely distinctive force field corrections. Compared to forces on the Earth exerted by the lunar attraction, the Moon is subjected to an attraction from the Earth and solid tides with higher magnitude. On the other hand, little atmospheric drag is caused because of its rare density. For the Mars or Venus, exact atmosphere density model will be the key factor for gravity field determination [4].

Impact by Solar Radiation Pressure: 'Cannonball model' used for default solar radiation pressure correction model in GEODYN-II software is not fully satisfied. A simulated model with a little more real condition from Chang'E-1 is tested here. The model is considered to be a combination of a main cube (one of sides is $1.5\text{m} \times 1.5\text{m}$) and two solar panels(one is $2.5\text{m} \times 2.5\text{m}$). The true reflectivity is not measured, and specular and diffuse reflectivity are assumed to 0.04 and 0.16, respectively. Compared to cannonball-model, Figure 3 shows the visible difference between them. For Z-component accelerate along to the lunar spin axis, the maximum error is up to more than 80%. Otherwise, the maximum of Y-component accelerate, which is normal to Z axis in lunar equatorial plane, is almost 5 times as size as that of cannonball.

For high precise gravity determination, the long term or periodic term effects on orbital elements from solar radiation pressure must be calculated. With understanding the relationship between them, an effective method can be made to clear the residuals. According to perturbation in the Gauss form equations[5], the variations of six orbital elements can be expressed with Y and Z component accelerates caused by solar radiation pressure mentioned above. The period variation of angle between the direction to the Sun and Z axis is considered.

In group 1 of functions, a , e , i , Ω , w , M are orbital elements, a_y , a_z are Y , Z components of accelerates caused by solar radiation pressure, respectively. They are also functions of time or true anomaly, f . Because the terms are too lengthy and complicated, they are not showed here.

Furthermore, for the high precise application, other important factors should be verified, including the choice of JPL ephemeredes, step-size for the integration, prediction of solar flux, planetary magnetic field, the size and orientation of forces by thruster, and some empirical force models.

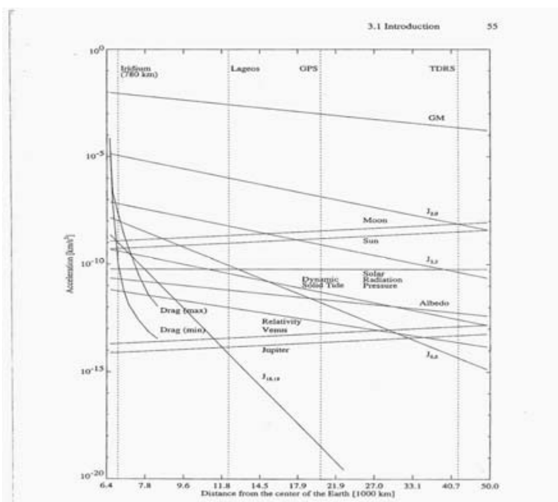
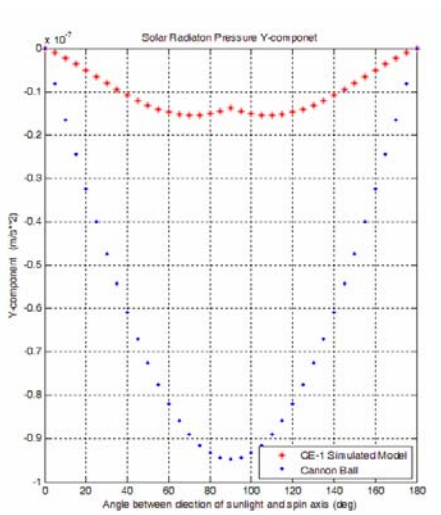


Fig.1 Order of magnitude of various perturbations of satellite orbit [3]



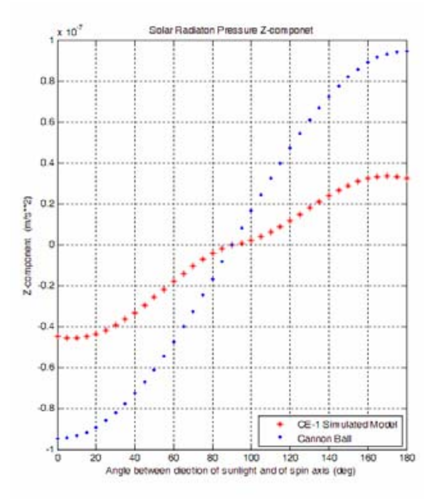


Fig 3. Comparison with ‘Cannonball’ model and real model of Chang’E-1 in Y , Z components

Reference: [1] Pavlis D.E. et. al.(2001) GEODYN Operations Manuals, Raytheon ITTS Contractor Report, Lanham, MD. [2] Helmut Moritz, Physical Geodesy, 2nd edition, 2005 [3] Satellite Geodesy, 2001 [4] M.T. Zuber et. al. (2007) Preliminary results from the Mars Reconnaissance Orbiter Radio Science Gravity Investigatio. [5] Brouwer D ad G M Clemence, Method of Celestial Mechanics, Acad. Press(1961)

$$\frac{da}{df}=\frac{2p^2ae}{(1+e\cos f)^{3/2}GM(1-e^2)}[(a_y(\sin\Omega\cos(w+f)+\cos\Omega\sin(w+f)\cos i)+$$

$$+a_z\sin(w+f)\sin i)\sin f+(1+e\cos f)(a_y(-\sin\Omega\sin(w+f)$$

$$+\cos\Omega\cos(w+f)\cos i)+a_z\sin(w+f)\sin i)]$$

$$\frac{de}{df}=\frac{p^2}{(1+e\cos f)^2GM}[(a_y(\sin\Omega\cos(w+f)+\cos\Omega\sin(w+f)\cos i)$$

$$+a_z\sin(w+f)\sin i)\sin f+\left(\cos f+(1+e\cos f)\cos f+\frac{e}{1+e\cos f}\right)$$

$$*\left(a_y\left(-\sin\Omega\sin(w+f)\right)+\cos\Omega\sin(w+f)\cos i\right)+a_z\cos(w+f)\sin i)]$$

$$\frac{di}{df}=\frac{p^3}{(1+e\cos f)^3GMa(1-e^2)}\left(-a_y\cos\Omega\sin i+a_z\cos i\right)\cos(w+f)$$

$$\frac{d\Omega}{df}=\frac{p^3}{(1+e\cos f)^3GMa(1-e^2)}\frac{\sin(w+f)}{\sin i}\left(-a_y\cos\Omega\sin i+a_z\cos i\right)$$

$$\frac{dw}{df}=\ldots\ldots\quad,\quad\frac{dM}{df}=\ldots\ldots\qquad\text{(func.1)}$$